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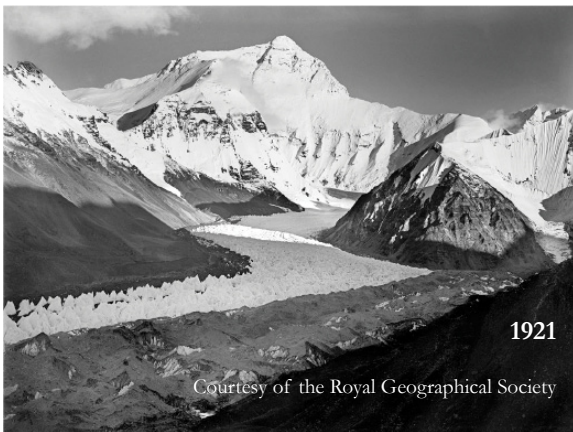
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# Fate of Mountain Glaciers in the Anthropocene

*A Report by the Working Group Commissioned by the Pontifical Academy of Sciences*



Main Rongbuk Glacier (see inside page)

May 11, 2011



*The working group consists of glaciologists, climate scientists, meteorologists, hydrologists, physicists, chemists, mountaineers, and lawyers organized by the Pontifical Academy of Sciences at the Vatican, to contemplate the observed retreat of the mountain glaciers, its causes and consequences. This report resulted from a workshop in April 2011 at the Vatican.*

### Cover Image:

Main Rongbuk Glacier

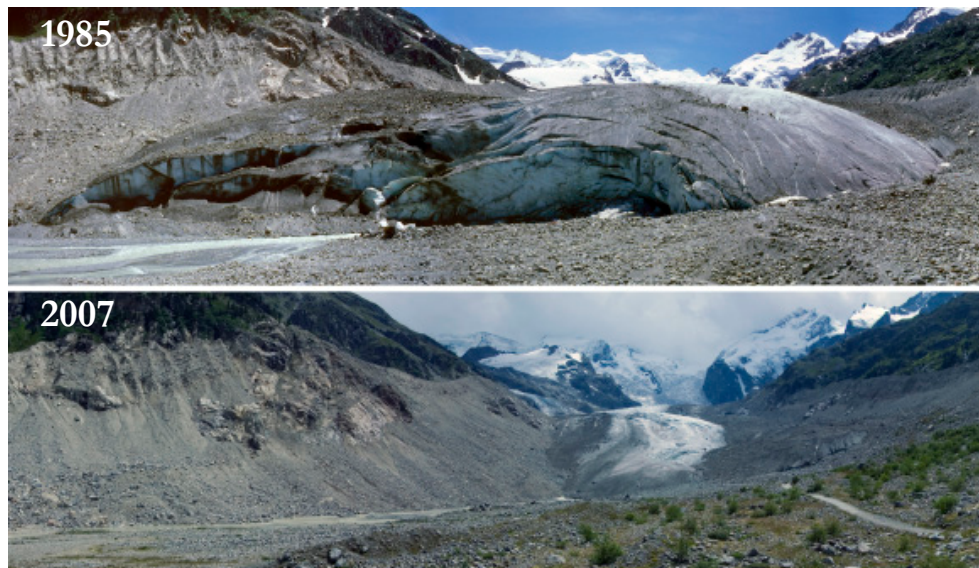
Location: Mount Everest, 8848 m, Tibet Autonomous Region

Range: Mahalangur Himal, Eastern Himalayas

Coordinates: 27°59'15"N, 86°55'29"E

Elevation of Glacier: 5,060 - 6,462 m

Average Vertical Glacier Loss: 101 m, 1921 - 2008



*Morteratsch glacier (Alps). Courtesy of J. Alean, SwissEduc*

## Declaration by the Working Group

**W**E CALL ON ALL PEOPLE AND NATIONS to recognise the serious and potentially irreversible impacts of global warming caused by the anthropogenic emissions of greenhouse gases and other pollutants, and by changes in forests, wetlands, grasslands, and other land uses. We appeal to all nations to develop and implement, without delay, effective and fair policies to reduce the causes and impacts of climate change on communities and ecosystems, including mountain glaciers and their watersheds, aware that we all live in the same home. By acting now, in the spirit of common but differentiated responsibility, we accept our duty to one another and to the stewardship of a planet blessed with the gift of life.

We are committed to ensuring that all inhabitants of this planet receive their daily bread, fresh air to breathe and clean water to drink as we are aware that, if we want justice and peace, we must protect the habitat that sustains us. The believers among us ask God to grant us this wish.

# I. Summary

## Receding Glaciers Require Urgent Responses



*Kyetrak Glacier 1921. Location: Cho Oyu, 8201 m, Tibet Autonomous Region; Eastern Himalayas . Elevation of Glacier: 4,907 – 5,883 m. Courtesy of Royal Geographical Society*



*Kyetrak Glacier 2009; Photography 2009: Courtesy of Glacier Works*



**Anthropocene:** Aggressive exploitation of fossil fuels and other natural resources has damaged the air we breathe, the water we drink, and the land we inhabit. To give one example, some 1000 billion tons of carbon dioxide and other climatically important “greenhouse” gases have been pumped into the atmosphere. As a result, the concentration of carbon dioxide in the air now exceeds the highest levels of the last 800,000 years. The climatic and ecological impacts of this human interference with the Earth System are expected to last for many millennia, warranting a new name, **THE ANTHROPOCENE**, for the new “man-made” geologic epoch we are living in.

**Glacier Retreat:** Glaciers are shrinking in area worldwide, with the highest rates documented at lower elevations. The widespread loss of glaciers, ice, and snow on the mountains of tropical, temperate, and polar regions is some of the clearest evidence we have for a change in the climate system, which is taking place on a global scale at a rapid rate. Long-term measurement series indicate that the rate of mass loss has more than doubled since the turn of the century. Melting mountain glaciers and snows have contributed significantly to the sea level rise observed in the last century. Retreat of the glaciers in the European Alps has been observed since the end of the ‘Little Ice Age’ (first part of the 19th century), but the pace of retreat has been much faster since the 1980s. The Alpine glaciers have already lost more than 50% of their mass. Thousands of small glaciers in the Hindukush-Himalayan-Tibetan region continue to disintegrate, a threat to local communities and the many more people farther away who depend on mountain water resources. Robust scenario calculations clearly indicate that many mountain ranges worldwide could lose major parts of their glaciers within the coming decades.

The recent changes observed in glacial behaviour are due to a complex mix of causal factors that include greenhouse gas forcing together with large scale emissions of dark soot particles and dust in “brown clouds”, and the associated changes in regional atmospheric energy and moisture content, all of which result in significant warming at higher altitudes, not least in the Himalayas.

**Perspective on Past Changes:** In response to the argument that “since the Earth has experienced alternating cold periods (ice ages or glacials) and warm periods (inter-glacials) during the past, today’s climate and ice cover changes are entirely natural events”, we state:

*The primary triggers for ice ages and inter-glacials are well understood to be changes in the astronomical parameters related to the motion of our planet within the solar system and natural feedback processes in the climate system. The time scales between these triggers are in the range of 10,000 years or longer. By contrast, the observed human-induced changes in carbon dioxide, other greenhouse gases, and soot concentrations are taking place on 10-100 year timescales—at least a hundred times as fast. It is particularly worrying that this release of global warming agents is occurring during an interglacial period when the Earth was already at a natural temperature maximum.*

**Three Recommended Measures:** Human-caused changes in the composition of the air and air quality result in more than 2 million premature deaths worldwide every year and threaten water and food security —especially among those “bottom 3 billion” people who are too poor to avail of the protections made possible by fossil fuel use and industrialization. Since a sustainable future based on the continued extraction of coal, oil and gas in the “business-as-usual mode” will not be possible because of both resource depletion and environmental damages (as caused, e.g., by dangerous sea level rise) we urge our societies to:

- I. Reduce worldwide carbon dioxide emissions without delay, using all means possible to meet ambitious international global warming targets and ensure the long-term stability of the climate system.** All nations must focus on a rapid transition to renewable energy sources and other strategies to reduce CO<sub>2</sub> emissions. Nations should also avoid removal of carbon sinks by stopping deforestation, and should strengthen carbon sinks by reforestation of degraded lands. They also need to develop and deploy technologies that draw down excess carbon dioxide in the atmosphere. These actions must be accomplished within a few decades.

- II. Reduce the concentrations of warming air pollutants (dark soot, methane, lower atmosphere ozone, and hydrofluorocarbons) by as much as 50%,** to slow down climate change during this century while preventing millions of premature deaths from respiratory disease and millions of tons of crop damages every year.
- III. Prepare to adapt to the climatic changes, both chronic and abrupt, that society will be unable to mitigate.** In particular, we call for a global capacity-building initiative to assess the natural and social impacts of climate change in mountain systems and related watersheds.

*The cost of the three recommended measures pales in comparison to the price  
the world will pay if we fail to act now.*



## II. Specific Findings and Recommendations

Mountain glaciers are lethally vulnerable to ongoing climate change



*Qori Kalis outlet glacier (the largest outlet glacier from the Quelccaya Ice Cap in the southern Andes of Peru). Credit: Lonnie Thompson, Ohio State University*

### Anthropocene: A New Geological Epoch

The last two centuries have seen an unprecedented expansion of human population and exploitation of Earth's resources. This exploitation has caused increasingly negative impacts on many components of the Earth System—on the air we breathe, the water we drink, and the land we inhabit. Humanity is changing the climate system through its emissions of greenhouse gases and heat-absorbing particulate pollution. Today's

atmospheric concentration of carbon dioxide, the principal greenhouse gas, exceeds all other maxima observed over the last 800,000 years. Vast transformations of the land surface, including loss of forests, grasslands, wetlands, and other ecosystems, are also causing climate change. In recognition of the fact that human activities are profoundly altering these components of the Earth System, Nobel Laureate Paul Crutzen has given the name **ANTHROPOCENE** to the new geological epoch we have created for ourselves.

An expert group of scientists met under the auspices of the Pontifical Academy of Sciences at the Casina Pio IV in the Vatican from 2 to 4 April 2011 to discuss the fate of mountain glaciers in the Anthropocene and consider the responses required to stabilize the climate change affecting them. This group's consensus statement is a warning to humanity and a call for fast action—to mitigate global and regional warming, to protect mountain glaciers and other vulnerable ecosystems, to assess national and local climate risks, and to prepare to adapt to those climate impacts that cannot be mitigated. The group also notes that another major anthropogenic risk to the climate system is from the threat of nuclear war, which can be lessened by rapid and large reductions in global nuclear arsenals.

## The Earth Is Warming and the Impacts of Climate Change Are Increasing

Warming of the Earth is unequivocal. Most of the observed increase in globally averaged temperature since the mid-20th century is 'very likely'—defined as more than 90% likely—to be the result of the observed increase in anthropogenic greenhouse gas concentrations. This warming is occurring in spite of masking by cooling aerosol particles—many of which are co-emitted by CO<sub>2</sub>-producing processes.

Some of the current and anticipated impacts of climate change include losses of coral reefs, forests, wetlands, and other ecosystems; a rate of species extinction many times faster than the historic average; and water and food shortages for many vulnerable peoples. Increasing sea level rise and stronger storm surges threaten vulnerable ecosystems and peoples, especially those in low-lying islands and coastal nations. The loss of mountain glaciers discussed here threatens downstream populations, especially during the dry season when glacial runoff is most needed.

## The Earth's Glaciers Are Retreating: Causes and Consequences

The widespread loss of ice and snow in the world's mountain glaciers is some of the clearest evidence we have for global changes in the climate system. The present losses of mountain glaciers cause more than 1 mm per year of sea level rise, or about one-third of the observed rate. In the most recent part of the Anthropocene, much of the reduction of glacier mass and length in tropical, temperate, and polar regions results from the observed increases in greenhouse gases and the increases in sunlight-absorbing particles such as soot, from inefficient combustion processes, and dust, from land cover change.

As shown in the 2007 report of the Intergovernmental Panel on Climate Change, extrapolations from mass change studies carried out on about 400 selected glaciers worldwide indicate a present average annual thinning of about 0.7 m in water equivalent. The equilibrium line between accumulation and ablation area of a glacier has shifted upward by several hundred meters in most mountain ranges compared to the mid-1970s. For many glaciers in lower mountain ranges, the snow line at the end of summer is above the maximum altitude of the mountains, leaving them lethally

vulnerable to ongoing climate change. Glacier fragmentation is occurring in most areas, leaving the resultant smaller glacier closer to disappearing altogether.

Glacier areas are observed to be shrinking worldwide, with the highest rates at lower elevations. Large glaciers lose their tongues, leaving unstable moraines and fragilely dammed lakes behind, such as Imja Lake in Nepal. Such fragile dams have been subject to failure, causing outburst floods that ravage the already fragile infrastructure of poor communities downstream.

In Western North America, human disturbance is increasing the dust load from the deserts of the Colorado Plateau and Great Basin, which darkens and thus shortens the snow season in the Colorado Rocky Mountains by 4–7 weeks. The dust particles also add to atmospheric warming by absorbing sunlight. Elsewhere the widespread “brown clouds” of black carbon from inefficient combustion could have a large impact in regions such as the Himalayas. We have very limited—and in some cases no—energy and mass balance studies that quantify the black carbon effects on snow and ice in such remote mountain areas. The impacts that we do understand with detailed measurements in the Western North America provide insight into the snow and glacier responses in other similarly affected regions.

The amounts and rates of glacier mass loss differ by region, and so also do the associated impacts on seasonal water availability in close-by valleys and neighbouring lowlands. In regions with dry and warm seasons, such as Central Asia, mountains and their glaciers and winter snows are like “water towers” that store water for millions of people. Their behaviour can be deceptive. Glacial mass loss can cause an initial temporary increase in runoff downstream from water that has been stored for a long time, as has been observed in several basins, but runoff inevitably decreases as the parent glaciers decrease further.

Mountain glaciers serve another critical function: they preserve detailed information on past climate and the ability of glaciers to respond to different climate variables. This

makes glaciers powerful tools for understanding past and present climate dynamics. The full potential of mountain glaciers as climate research tools is just beginning to be realized. The additional research needed to reduce uncertainties, delineate governing processes, and quantify regional impacts could have a big payoff. It is time we pay more careful attention to mountain glaciers before their archives are lost forever.

## Avoiding “Dangerous Anthropogenic Interference” Requires Clear and Binding Climate Targets

The goal of a climate policy is to stabilize greenhouse gas emissions at a level that would prevent “dangerous anthropogenic interference with the climate system” and “allow ecosystems to adapt naturally to climate change, ensure that food production is not threatened and enable economic development to proceed in a sustainable manner”, as laid down in Article 2 of the UN Framework Convention on Climate Change.

The temperature guardrail for avoiding “dangerous anthropogenic interference” is now proposed to be at 2° C warming (above the pre-industrial level), although many scientists argue and many nations agree that 1.5° C is a safer upper limit. Scientific, political, and economic considerations have contributed to the identification of this threshold, which has been adopted by the international climate negotiations. The Earth has already warmed by 0.75° C since 1900 AD, and might reach some 2° C by the year 2100 AD, even if today’s greenhouse gas concentrations are not increased further and air pollution is curbed for humanitarian reasons. There is a risk that the warming can well exceed 3° C if emissions of greenhouse gases continue to increase at present rates. Thus exceeding the 2° C climate target is a real and serious possibility.

## Rapid Mitigation Is Required If Warming and Associated Impacts Are to Be Limited

Understanding the causes of climate change, as well as its current and projected impacts, presents society the opportunity to avoid unmanageable impacts through mitigation and to manage unavoidable impacts through adaptation. The time to act is now if society is to have a reasonable chance of staying below the 2° C guardrail.

**Possible mitigation by reducing carbon dioxide emissions and expansion of carbon sinks:** CO<sub>2</sub> is the largest single contributor to greenhouse warming. While more than half of CO<sub>2</sub> is absorbed by ocean and terrestrial sinks within a century, approximately 20% remains in the atmosphere to cause warming for millennia. Every effort must be made to cut CO<sub>2</sub> direct emissions from fossil fuel burning, cut indirect emissions by avoiding deforestation, and expand forests and other sinks, as fast as possible to avoid the profoundly long warming and associated effects that CO<sub>2</sub> causes.

**Possible mitigation by reducing the emission of non-CO<sub>2</sub> short-lived drivers:** The second part of an integrated mitigation strategy is to cut the climate forcers that have short atmospheric lifetimes. These include black carbon soot, tropospheric ozone and its precursor methane, and hydrofluorocarbons (HFCs). Black carbon (BC) and tropospheric ozone strongly impact regional as well as global warming. Cutting the short-lived climate forcers using existing technologies can reduce the rate of global warming significantly by the latter half of this century, and the rate of Arctic warming by two-thirds, provided CO<sub>2</sub> is also cut.

Reducing local air pollutants can save about 2 million lives each year, increase crop productivity, and repair the ability of plants to sequester carbon. Black carbon management should be part of an integrated aerosol management strategy, to ensure that BC warming is cut faster than the cooling from other aerosols. In many areas, there is a real potential to reduce the BC and dust loading that accelerates glacier



and snow melt, by: reducing BC emissions from traditional cook stoves by replacing them with energy efficient and less polluting cook stoves, trapping BC from diesel combustion with filters, and restabilising desert surfaces and other soils to reduce their dust emissions.

HFCs are synthetic gases and are the fastest growing climate forcer in many countries. The production and use of HFCs can be phased down under the Montreal Protocol on Substances that Deplete the Ozone Layer, while leaving the downstream emissions of HFCs in the Kyoto Protocol. This would provide the equivalent of 100 gigatonnes of CO<sub>2</sub> in mitigation by 2050 or earlier. The Montreal Protocol is widely considered the world's best environmental treaty; it has already phased out 98% of nearly 100 chemicals that are similar to HFCs, for a net of 135 gigatonnes of climate mitigation between 1990 and 2010.

In sum, air pollution and climate change policies are still treated as if they were two separate problems, when they actually represent the same scourge. Emission sources for air pollutants and greenhouse gases coincide, and a combined policy strategy reduces the cost of counteracting both these threats to human health and the well-being of society. These mitigation strategies must be pursued simultaneously and as aggressively as the dictates of science demand. Together they have the potential to restore the climate system to a safe level, and reduce climate injustice. But time is short. Warming and associated effects in the Earth System caused by the cumulative CO<sub>2</sub> emissions that remain in the atmosphere for millennia may soon become unmanageable.

## Adaptation Must Begin Now

Because of the time lag between mitigation action and climate response, vulnerable ecosystems and populations will face significant climate impacts and possibly unacceptable risks even with ultimately successful mitigation. Therefore, in addition to mitigation, adaptation must also start now and be pursued aggressively.

We cannot adapt to changes we cannot understand. Adaptation starts with assessment. An international initiative to observe and model mountain systems and their watersheds with high spatial resolution, realistic topography, and processes appropriate to high altitudes is a prerequisite to strengthening regional and local capacities to assess the natural and social impacts of climate change.

## Glacier Measurements Need to Be Expanded and Improved

We need to characterize the critical climate and radiative forcings on mountain glaciers and their corresponding responses that are not yet sufficiently understood. Among these, we must improve our understanding of the regional differences in glacial response around the globe in terms of the regional changes in climate and in absorbing impurities. Our observations of the glacier volumes, precipitation, and respective changes in mountain catchments are severely limited. This limits our ability to create scenarios of future runoff. Our climate models cannot resolve the rough terrain of mountainous regions and therefore poorly represent precipitation, temperature variations, and capture of aerosol loading. Likewise, our modeling and monitoring of the connections between the changes in an upstream glacierised water catchment to water resources at the downstream basin scale are at the initial stages.

The remoteness and dangerous nature of work above 6000 m is one reason why we have few detailed measurements, other than of glacier length and size, in high mountain systems like the Himalayas and Andes. Current remote sensing technologies can detect changes in glacier and snow extent, but do not quantify relative forcings or provide important snow and ice properties, such as grain size, local impurities, and surface liquid water content. However, airborne and space-borne imaging spectrometers will soon allow us to make spatially comprehensive measurements of these surface properties. Put in context by more extensive observations from large-scale field campaigns, and in situ energy balance and mass balance measurements, imaging spectrometers will be used to construct and validate the next generation of high resolution glacier mass balance models. Quantitative observations are the key.

## Geoengineering: Further Research and International Assessment Are Required

Geoengineering is no substitute for climate change mitigation. There are many questions that need to be answered about potential irreversibilities, and of the disparities in regional impacts, for example, before geoengineering could be responsibly considered. There has not been a dedicated international assessment of geoengineering. Geoengineering needs a broadly representative, multi-stakeholder assessment performed with the highest standards, based for example on the IPCC model. The foundation for such an assessment has to be much broader with deeper scientific study than there has been a chance to carry out thus far.

It may be prudent to consider geo-engineering if irreversible and catastrophic climate impacts cannot be managed with mitigation and adaptation. A governance system for balancing the risks and benefits of geoengineering, and a transparent, broadly consultative consensus decision-making process to determine what risks are acceptable must be developed before any action can be taken.

## Individuals and Nations Have a Duty to Act Now

Humanity has created the *Anthropocene* era and must live with it. This requires a new awareness of the risks human actions are having on the Earth and its systems, including the mountain glaciers discussed here. It imposes a new duty to reduce these risks. Failure to mitigate climate change will violate our duty to the vulnerable of the Earth, including those dependent on the water supply of mountain glaciers, and those facing rising sea level and stronger storm surges. Our duty includes the duty to help vulnerable communities adapt to changes that cannot be mitigated. All nations must ensure that their actions are strong enough and prompt enough to address the increasing impacts and growing risk of climate change and to avoid catastrophic irreversible consequences.

We call on all people and nations to recognise the serious and potentially irreversible impacts of global warming caused by the anthropogenic emissions of greenhouse gases and other pollutants, and by changes in forests, wetlands, grasslands, and other land uses. We appeal to all nations to develop and implement, without delay, effective and fair policies to reduce the causes and impacts of climate change on communities and ecosystems, including mountain glaciers and their watersheds, aware that we all live in the same home. By acting now, in the spirit of common but differentiated responsibility, we accept our duty to one another and to the stewardship of a planet blessed with the gift of life. We are committed to ensuring that all inhabitants of this planet receive their daily bread, fresh air to breathe and clean water to drink, as we are aware that, if we want justice and peace, we must protect the habitat that sustains us.

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*Working Group Co-chairs are underlined*